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Effect of thickness and shade of CAD/CAM composite on the light transmission from different light-curing units

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Abstract: The thickness and shade of a restoration will affect the transmission of light from the light-curing unit (LCU). This study determined the power (mW), spectral radiant power (mW/nm), and beam profile of different LCUs through various thicknesses and shades of a CAD-CAM resin composite (BRAVA Block, FGM). Five thicknesses: 0.5; 0.75; 1.0; 1.5, and 2.0 mm, in three shades: Bleach; A2 and A3.5 of a CAD-CAM resin (n = 5). Two single-peak LCUs: EL, Elipar DeepCure-S (3M Oral Care); and OP, Optilight Max (Gnatus), and one multiple-peak LCU: VL, VALO Grand (Ultradent), were used. The LCUs were positioned touching the surface of the BRAVA Block. The power and emission spectrum were measured using a fiberoptic spectrometer attached to an integrating sphere, and the beam profiles using a laser beam profiler. The effect of the material thickness on the light attenuation coefficients was determined. VL and EL delivered more homogeneous beam profiles than OP. The type of the BRAVA Block had a significant effect on the transmitted power, and wavelengths of transmitted light ($p < 0.001$). There was an exponential reduction in the power and emission spectrum as the thickness of the BRAVA Block increased ($p < 0.001$). The light transmission through the A2 shade was least affected by the thickness ($p < 0.001$). The attenuation coefficient was higher for the violet light and higher for A3.5 than the A2 or Bleach shades. No violet light from the VL could be detected at the bottom of 2.0 mm of the BRAVA Block.

Keywords: Light; Polymerization; Computer-Aided Design; Composite Resins.

Introduction

The use of computer-aided design and manufacturing (CAD-CAM) technology has increased exponentially in recent years.[1] This technology allows the prepared teeth to be scanned, the restoration designed, milled out of a CAD-CAM material and adhesively cemented to the tooth in just one appointment.[2,3] The two primary restorative materials used in CAD-CAM technology are ceramic and resin composite-based materials.[4,5] Despite having inferior mechanical and aesthetic properties than ceramic materials,[6] resin composites have been proposed as a more economical alternative that can also be repaired intraorally.[2,4] Some CAD-CAM materials that are called hybrid ceramics, consist of a ceramic substructure surrounded by resin.[3] These materials are available in different shades and can be milled in various thicknesses.[7]

The adhesive bonding process between the tooth and the restoration is a crucial step to ensure the success of the restoration.[8,9] Depending on the thickness of the restorative material, two types of resin cement are recommended: either a purely light-polymerized resin cement, or a dual-cured resin cement.[10-13] To ensure the optimum properties of both types of cements, in both cases, sufficient light must pass through the restorative material to photocure the resin cement.[14-16] Using a thicker restorative material and a darker or opaque shade of the block will reduce the light transmission through the restoration. This could compromise both the bond to the tooth and the mechanical properties of the cement.[17,18]

The need for increasingly whiter colored and more color-stable luting cements has resulted in manufacturers using the new generation of Norrish Type I photoinitiators in their resin cement, so that they can reduce the amount of camphorquinone,[19,20] because camphorquinone has a bright yellow color.[21] Many of these alternative photoinitiators require violet light, and light manufacturers have developed light-emitting diode (LED) light curing units (LCUs) that emit both violet and blue light.[22-25] However, the wavelength of violet light (390–410 nm) is shorter than blue light (420–470 nm), and violet light does not penetrate through the restorative material as well as blue light.[24-28]

The type of LCU and the combination of the shade, opacity, and thickness of the CAD-CAM material all affect the power and wavelengths of light transmitted through the restorative material.[7,29-31] The irradiance value at the light tip is the radiant power (usually expressed in mW) divided by the area of the light tip (usually expressed in cm^2). More expensive LCUs are often more powerful and have a greater active tip area than budget LCUs. However, the cost of LCU does not always correlate with the irradiance delivered because the irradiance from the LCU can be increased by reducing the diameter of the light tip[8,32] and many budget-cost lights have a small 6 to 7 mm diameter light tip. Most studies only analyze the effect of light transmission on ceramic materials.[11,12,17] However, the characteristics and composition of the resin-based composite materials can also affect the beam profile of the light as it passes through the material, the wavelengths of the transmitted light, and the attenuation coefficient.[7,26,33-35]

Most budget-cost light-curing units usually transmit less power through different thicknesses and shades of CAD-CAM materials, which can affect the photo-activation of the resin based the luting cement.[7] Therefore, the purpose of this study was to evaluate the radiant power (mW), the spectral radiant power (mW/nm) of the transmitted light, and beam profiles of different LCUs through different thicknesses and shades of a glass-ceramic resin composite used for CAD-CAM restorations. The null hypothesis was that the thickness and shade of the CAD-CAM material would not affect the light transmission, wavelengths of transmitted light, beam profile or the attenuation coefficients.

Methodology

Study design

Low translucency CAD/CAM blocks (BRAVA Block; FGM, Joinvile, SC, Brazil) that the manufacturer claims to be a glass-ceramic resin composite were used in 5 different thicknesses, and three shades. Two single-peak LCUs: EL (Elipar DeepCure-S; 3M Oral Care, St. Paul, USA) and OP (Optilight Max; Saevo, Ribeirão Preto, Brazil) and one multiple-peak LCU: VL (VALO Grand; Ultradent, South Jordan, USA) were used. The specifications of these LCUs are reported in Table 1. The LCUs were positioned at 0 mm from the surface of the CAD/CAM material. The power and emission spectrum were obtained using a fiberoptic spectrometer attached to an integrating sphere. The light attenuation coefficients of all three LCUs and shades were calculated for each thickness of the CAD/CAM BRAVA blocks.

Table 1. The specifications of light-curing units (LCUs) used in this study.

LCUs	Serial number	LED LCU / wavelength emission	External Tip Diameter (mm)	Internal Tip Diameter (mm)	Irradiance (mW/cm²)	Manufacturer
Elipar DeepCure-S	1521087817	single-peak	9.8	9.0	1500	3M Oral Care, St Paul, USA
Optilight Max	881778249	single-peak	7.9	7.0	1580	Gnatus, Ribeirão Preto, Brazil
VALO Grand	MFG3227-5	multi-peak	15.1	12.0	1150	Ultradent, South Jordan, USA

Table 2. The specifications of CAD-CAM resin composite blocks used in this study.

LCUs	Composition	Shade	Serial number	Manufacturer
BRAVA Block	Methacrylate monomers, initiator, co-initiator, stabilizers, silane, glass-ceramic particles, silica, and pigments.	A2 LT/14L	A2LT051220	FGM, Joinvile, Brazil
		Bleach LT/14L	BLLT071120	
		A3.5 LT/14L	A35LT081220	

CAD-CAM resin composite preparation

The Bleach, A2, and A3.5 shades of low translucency CAD/CAM materials (Table 2) were glued to an acrylic plate with cyanoacrylate glue (Super Bonder; Loctite, Itapevi, Brazil) and sticky wax (Sticky Wax; Asfer, São Caetano do Sul, Brazil). The blocks (BRAVA Block; FGM) were sectioned into 14.5 mm X 14.5 mm slices (n = 5) that were: 0.5; 0.75; 1.0; 1.5, and 2.0 mm thick using a precision saw (IsoMet 1000; Buehler, Lake Bluff, USA) at 225 rpm under a 150g load and with copious water irrigation.

Total radiant power and emission spectrum

The total radiant power (mW), and spectral radiant power (mW/nm) from the 3 LCUs were determined. Five measurements of the total radiant power (mW) emitted between 350 and 550 nm and spectral radiant power (mW/nm) from the LCUs were measured using a fiber optic spectrometer (USB 4000; Ocean Insight, Orlando, USA) connected to a six-inch integrating sphere (LabSphere; North Sutton, USA). An internal calibration lamp (SCL 600; Labsphere) calibrated the system. The light transmission through the control (no interposing CAD/CAM material) and the 5 thicknesses: 0.5; 0.75; 1.0; 1.5, and 2.0 mm, for the three shades of the CAD/CAM materials was measured with the LCU tip at 0-mm through a 12 mm aperture in the integrating sphere.

Beam profile

The light beam profiles of light transmitted through the different thicknesses of glass-ceramic resin composite were measured using a laser beam profiler charge-coupled device (CCD) digital camera (Ophir-Spiricon) with a 50 mm focal length lens (SP620U; Ophir-Spiricon). The LCUs were mounted in a fixed orientation 0 mm away from the imaging screen or the CAD-CAM resin composites, facing toward the camera thus simulating all the conditions of the light transmission experiment. For the control condition, a diffusing surface 60-degree holographic diffusing screen (Edmund Optics, Barrington, USA) was positioned at the same focal distance from the digital camera. No screen was necessary when imaging the CAD/CAM blocks as they acted as the screen. Two blue filters (HOYA UV-VIS bandpass filter; Edmund Optics) and a reflective neutral density filter (Edmund Optics) that was spectrally flat were required to attenuate the light and correct the spectral response of the CCD camera sensor. The camera captured all the images at the same distance, position, and exposure time, thus making the images comparable. The images were collected using the beam analyzer software (BeamGage Professional version 6.14; Ophir-Spiricon, Logan, USA). The control two-dimensional beam profile images used the internal tip diameter (mm) of each LCU, and the "Optical Scaling" tool in the BeamGage Professional software produced calibrated the beam profile data in millimeters. The mean radiant power values (mW) previously obtained were then entered into the beam analyzer software to create color-coded calibrated tip images of the irradiance in mW/cm². The calibrated data from BeamGage Professional (Ophir-Spiricon) were then exported into OriginPro 2019 version 9.6. (OriginLab; Northampton, USA) where the images were all scaled to the same irradiance levels and x and y dimensions.

Light attenuation coefficient

The light attenuation coefficient (AC, mm^{-1}) characterizes how quickly incident light is attenuated when passing through a medium.[36,37] The greater the coefficient value, the greater the amount of attenuation, while a small value means that the medium has little effect on light transmission.[36,37] To evaluate the impact of the different specimens on the amount of transmitted light, the attenuation coefficient (AC, mm−1) was based on the Beer-Lambert law: $I(z) = Io\, e^{-\alpha z}$, where $I0$ is the initial light intensity measured in the absence of specimen, α is the attenuation coefficient, and z is the specimen thickness.

Statistical analysis

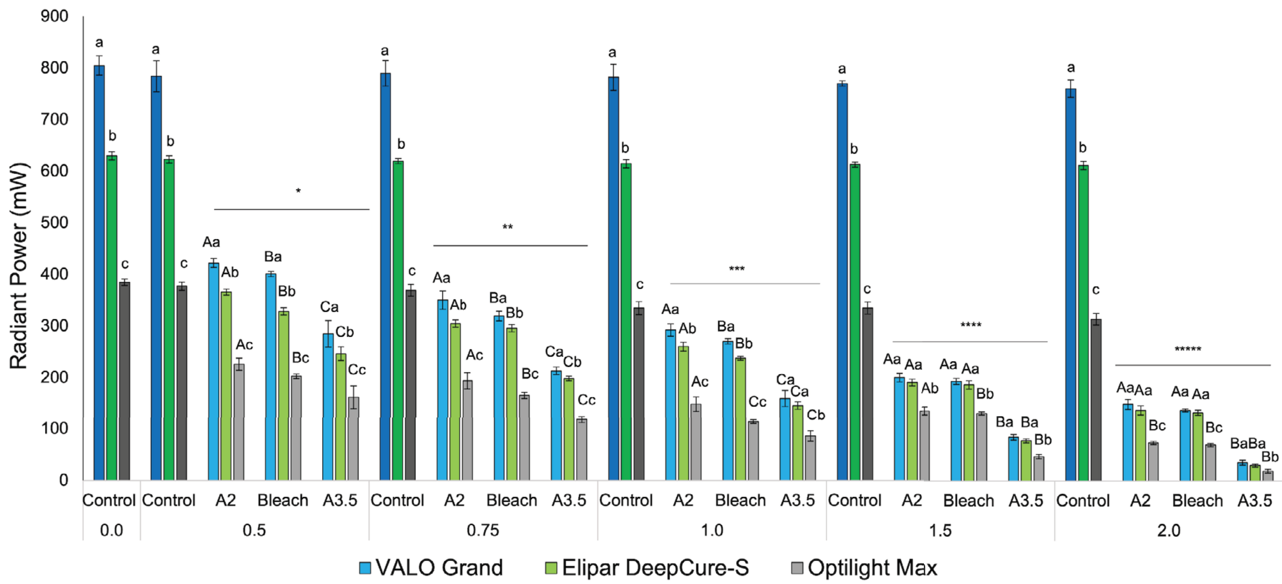
Radiant power data were analyzed for normal distribution and homoscedasticity using the Shapiro-Wilk and Levene's tests. Three-way ANOVA was used to compare the interactions between study factors: LCUs (3 levels), thicknesses (5 levels), and shades (3 levels) of CAD/CAM material. Multiple comparisons were made using Tukey's post-hoc test. All tests used a significance level of α = .05, and all analyses were performed using Sigma Plot 13.1 (Systat Software Inc, San Jose, USA). The emission spectra (nm/mW/cm²) and beam profiles were analyzed descriptively.

Results

The mean and standard deviation of radiant power (mW) from the three LCUs and transmitted through the different thicknesses and shades of the slices of CAD-CAM material are reported in Figure 1. The 3-way ANOVA (Table 3) reported that the shade, the thickness of a slice of CAD-CAM material and the LCU had significant effects ($p < 0.001$). The interaction between the LCU and thickness of the slice of CAD-CAM material, the interaction of LCU and CAD-CAM shade ($p < 0.001$), the interaction between the thickness and shade of CAD-CAM material ($p < 0.001$), and also between the LCU, thickness and shade were all significant ($p < 0.001$). The Tukey test showed that without a slice of the CAD-CAM material, the Valo (VL) LCU transmitted a significantly higher radiant power than EL, and OP delivered a significantly lower radiant power than both EL and OP ($p < 0.001$). The EL light delivered significantly higher radiant power than VL through the slices of CAD-CAM materials that were 0.5 and 0.75 mm thick, irrespective of the shade ($p < 0.001$). However, as the thickness increased to 1.0, 1.5 and 2.0 mm, the amount of light transmitted from VL was similar to EL (p =.321). The amount of light transmitted using OP was always significantly lower than from VL and EL, irrespective of the shade ($p < 0.001$).

The effects of thickness on the radiant power transmitted through the CAD-CAM resin composite for all shades and tested LCUs are shown in Figure 2. The greater the thickness, the lower the radiant power transmitted through the CAD-CAM materials, regardless of the shade and tested LCU ($p < 0.001$). The bleach shade transmitted the least radiant power through the slices of CAD-CAM material that were 0.5, 0.75 and 1.0 thick ($p < 0.001$). However, when the slices were 1.5 and 2.0 thick, the Bleach and A2 shades transmitted similar radiant power values (p =.108). The A3.5 shade transmitted the lowest radiant power through the slice of CAD-CAM material, regardless of thickness or tested LCU ($p < 0.001$).

The spectral radiant power (mW/nm) from the three LCUs without the interposition of a slice of CAD-CAM material (control) is shown in Figure 3. The thickness and shade of the slice of CAD-CAM material significantly affected the light attenuation for all wavelength spectra, irrespective of shade and LCU tested. The slices of CAD-CAM material in the A2 and Bleach shades that were 0.75 mm or greater had a lower attenuation effect on the emission spectrum than A3.5. Figure 3 shows that



*indicate a significant difference between thickness of the BRAVA CAD-CAM blocks.

Figure 1. Means and standard deviations of the radiant power (mW) of each LCU measured using an integrating sphere. Control (without the BRAVA CAD-CAM) and through the three different shades and five different thicknesses of BRAVA CAD-CAM. Different uppercase letters indicate a significant difference between shades. Different lowercase letters indicate significant difference between the LCU used (Tukey test, $p < 0.005$).

Table 3. Thee-way ANOVA for the emitted radiant power values (mW) emitted by 3 LCUs through the CAD-CAM/RC made in three shades and at five different thicknesses.

Source of variation	Sum of squares	DF	Mean of squares	F	p-value
LCU	1.028.674.158	2	514.337.079	4.996.926	< 0.001
Thickness	560.630.625	4	140.157.656	1.361.670	< 0.001
Shade	5.076.031.355	3	16.438.346	6.405.920	< 0.001
LCU x Thickness	31.114.954	8	3.889.369	37.786	< 0.001
LCU x Shade	496.749.326	6	82.791.554	804.343	< 0.001
Thickness x Shade	93.334.303	12	7.777.859	75.564	< 0.001
LCU x Thickness x Shade	14.603.146	24	608.464	5.911	< 0.001
Error	12.145.823	118	102.931		

the greater the thickness, the greater the influence on the emission spectrum transmitted through the CAD-CAM material, irrespective of the shade and LCU ($p < 0.001$). The violet wavelengths from VL were undetectable when the CAD-CAM thickness was 1.0 mm or greater (Figure 3A-C).

The beam profiles for the three LCUs at 0 mm distance are shown in Figure 4. The VL and EL had a more homogeneous beam profile than OM. The light transmission through the slices of the CAD-CAM materials for the three LCUs is shown in Figure 5. The light beam profiles showed that the light transmission was affected by the shade of the CAD-CAM material. The beam profiles show that the light transmission through the A2 shade was greater than Bleach only for 0.5- and 0.75-mm thick slices of CAD-CAM material, irrespective of the LCU tested (Figure 5). The beam profiles of the light transmitted through the shade A3.5 slice of CAD-CAM material was the most negatively affected (Figure 5).

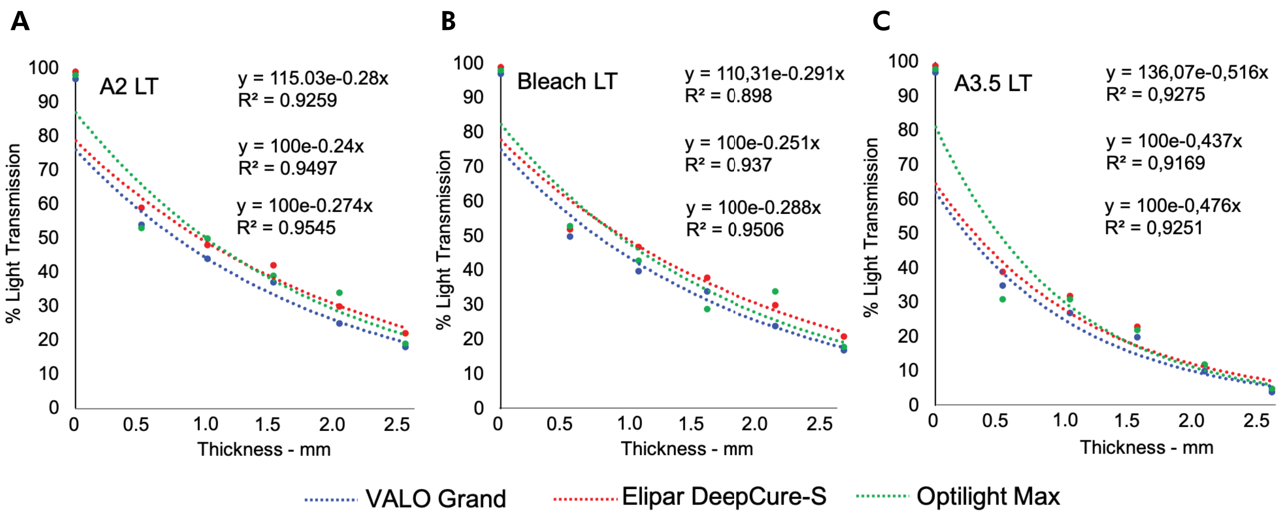


Figure 2. Attenuation (%) of the radiant power from the three LCUs transmitted through five different thicknesses and three shades (Bleach, A2 and A3.5) of BRAVA CAD-CAM.

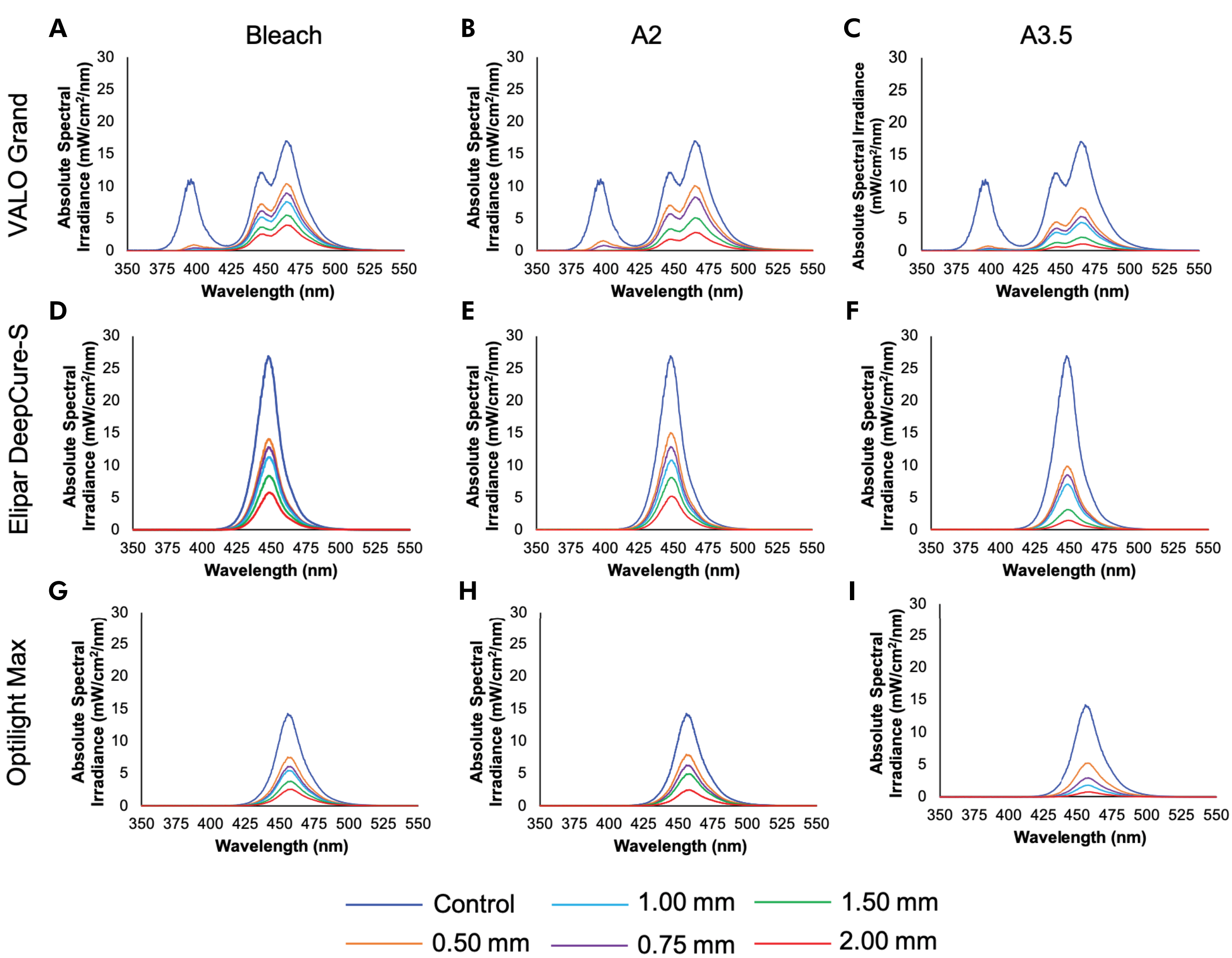


Figure 3. Wavelengths of light (mW/nm) from the LCUs through five different thicknesses of BRAVA CAD-CAM/RC in three shades (Bleach, A2 and A3.5): A-C: VALO Grand; D-F: Elipar DeepCure-S; G-I: Optilight Max.

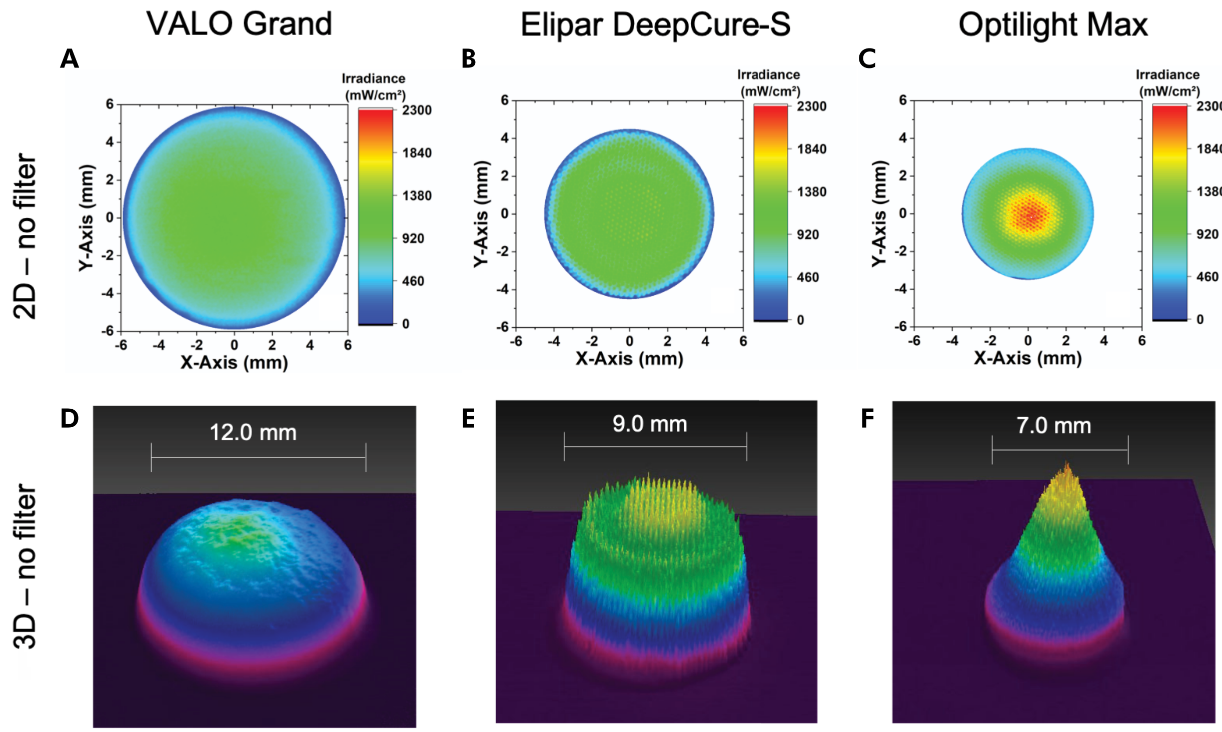


Figure 4. Two- and three-dimensional light beam profiles from the LCUs show the tip diameter and the irradiance (mW/cm^2) at 0 mm distance without any interposing material. All the images are on the same scale. Note the difference in tip diameters from the 3 LCUs and the 'hot spot' of high irradiance from the Optilight Max and the wider more homogeneous beam profiles for VALO Grand and Elipar DeepCure-S.

The attenuation coefficient of the emitted for the three LCUs with the interposition of a slice of CAD-CAM material for all shades are shown in Figure 6. The attenuation coefficient was higher for lower wavelength (violet light) emitted by VALO Grand and was higher for A3.5 shade than A2 and Bleach shades. As expected, the attenuation is more evident for violet light than for blue light (Figure 6A). As illustrated in Figure 3, the DeepCure-S and the Optilight emitted very little light below 420 nm, and thus the scale for these to LCUs was only extended to 420 nm.

Discussion

This study evaluated the influence of the thickness and shade of one brand of CAD-CAM material on the light transmission from single-peak and multiple-peak LCUs. The thickness and shade of the low translucency CAD-CAM material significantly influenced the radiant power, attenuation coefficients, and attenuation of the different wavelengths of light. The radiant power, spectral radiant power, attenuation coefficients, and homogeneity of the light emitted from the LCUs were affected differently by the thickness and shade of the Brava Block CAD-CAM material. Thus, the null hypotheses were rejected.

A thickness limit for the restorative material that will allow adequate polymerization of a light-polymerized resin cement should be considered.[12] The amount of light transmitted through the indirect restorative material may need to be increased by increasing the exposure time for the luting cement to be adequately polymerized.[3,7,11] Otherwise, inadequate polymerization of the luting material can cause postoperative sensitivity, debonding, or staining at the margins, and secondary caries, leading to restoration failure.[15,21]

The greater the thickness of the CAD/CAM material, the lower the transmitted radiant power (Figure 1). Using a darker shade or a thicker restoration, that is commonly used in endodontically treated or severally structurally compromised posterior teeth, the greater the amount of light attenuation means that less light will reach the luting resin-based material,[7] and this

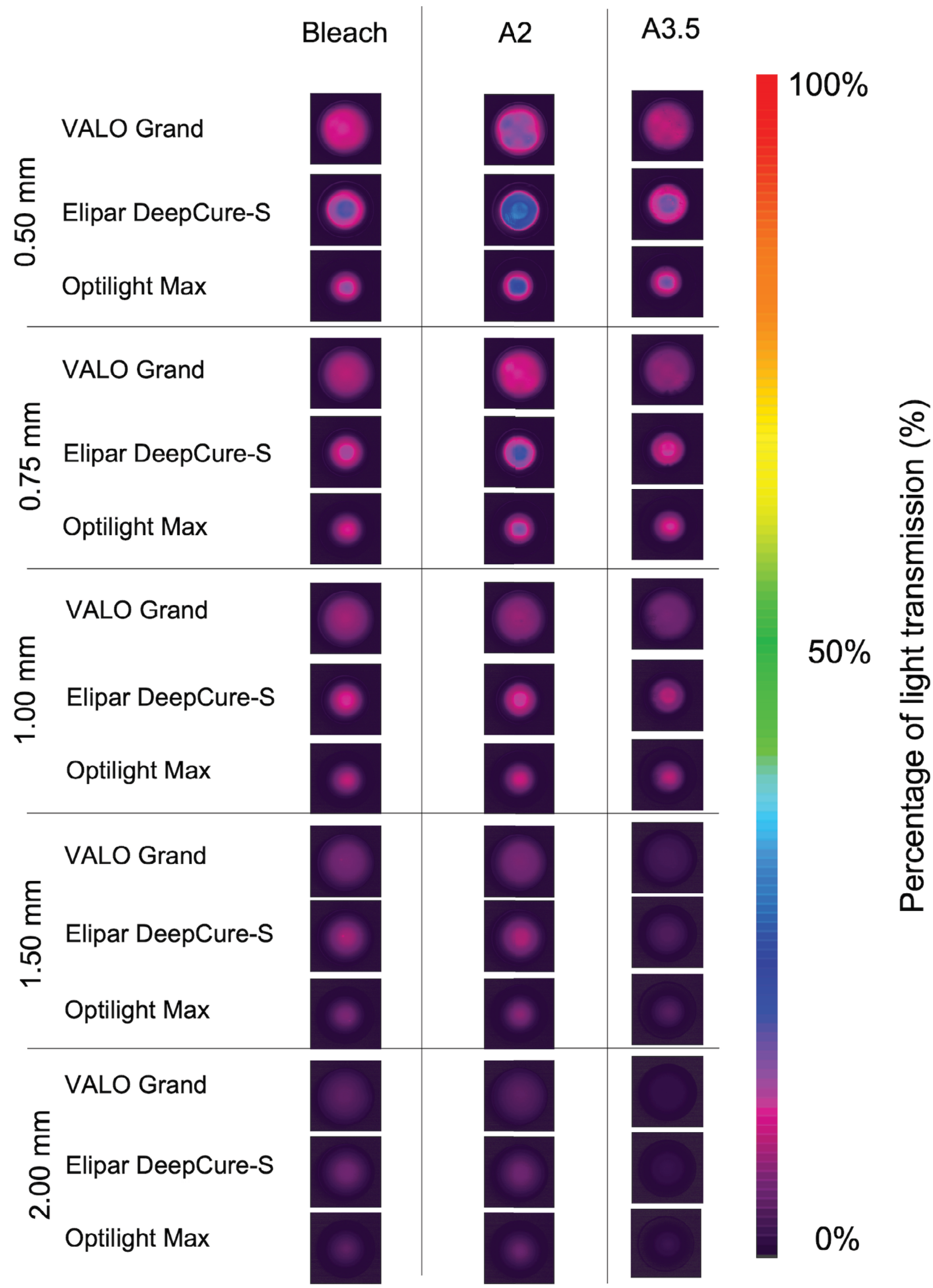


Figure 5. The two-dimensional representations of the beam profile recorded using the standard light output mode of the LCUs through the five thicknesses and Bleach, A2 and A3.5 shades of the BRAVA CAD-CAM blocks.

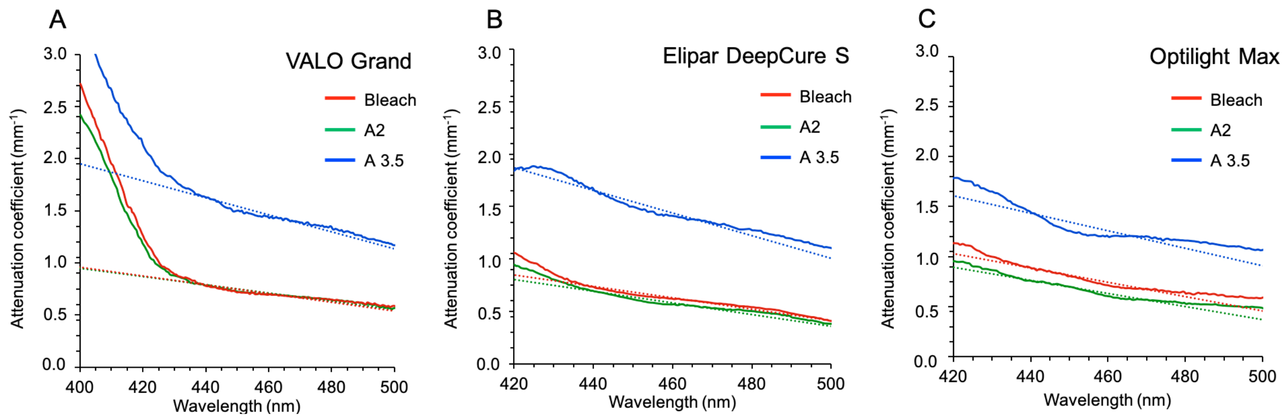


Figure 6. Light Attenuation Coefficients of the LCUs in relation to the different thicknesses of the different shades of the CAD/CAM blocks. Note the scale of the Elipar DeepCure-S and the Optilight finish at 420 nm because these lights emit very little light below 420 nm.

can negatively affect the polymerization process. For perpendicularly incident light source and at the closest exposure to the material surface, the amount of light transmitted through a CAD/CAM material decreases exponentially as the specimen thickness increases.[7] Consequently, an insufficient amount of light may reach the resin at the bottom of the proximal box in premolars and molars where the light must pass through several mm of CAD/CAM material. This may be the cause of premature failure in these areas that are furthest away from the light source. The conditions evaluated in this study were more challenging because a low translucency CAD-CAM material was used, resulting in more light attenuation than a higher translucency Brava Block, but the LCUs were used under ideal conditions, and the transmission was optimized. This may not always occur in the mouth.

Clinicians should recognize that the shade can significantly affect light transmission through the restorative material. Figure 3 shows that this light attenuation was greater in the Bleach shade, even though it is whiter than A2, and for the darker A3.5 shade. Darker resin composites tend to absorb more light, because the pigments attenuate the light.[30] Thus darker shades require a longer light exposure time, especially as the thickness increases.[14] The bleach shade also had higher light attenuation than the A2 shade. This occurred because the bleach shade has more white pigments and is consequently more opaque. These opaquers probably cause increased light scattering and absorbance compared to more translucent shades, such as A2.[21,29] When the darker and thicker slices of the CAD-CAM material were tested, the attenuation of the light was even more evident (Figures 1, 3 and 6). Therefore, longer exposure times and additional light activation from the buccal and lingual are recommended.

Many variables affect the amount of light energy transmitted through the material, such as the design and tip size of the LCU, spectral irradiance, exposure time, shade, and opacity of the restorative material.[15,16,25] In this study, the emission spectrum was significantly different among the three LCUs tested. With the increasing availability of brands and models of LCUs, the clinician may not know which LCU they should use. They may also base their decision on misleading data such as an averaged irradiance value.[25] In this study, VL delivered the lowest irradiance value because its tip is 12 mm in diameter compared to OP, which has a 7 mm tip (Table 1). Since the radiant exitance is the irradiance (mW/cm^2) at the light tip is the total radiant power (mW) emitted at the tip divided by the area of the light-emitting tip, this is an averaged radiant exitance (irradiance) value across the entire light tip. Reducing the tip diameter from 10 to 7 mm will halve the tip area and double the irradiance if the same power is delivered. It is not uncommon to see companies reduce the tip diameter to deliver an irradiance that is equivalent to or even greater than a more powerful higher-cost LCU that has a wider light tip.[25,32] When evaluating the beam profiles, the light from VL and EL sources was more uniform than the light from OP. The radiant exposure values were also higher for VL and EL. In practice, this lack of homogeneity and power can negatively affect the photo-activation of resins, especially at the restoration edges, ultimately leading to failure of the restoration.[9,15,27]

With the tendency to deliver lighter restorations, alternative photoinitiators different from camphorquinone were introduced.[13,19] Most require light in the violet range (below 410 nm) compared to materials that use only CQ, which requires a different wavelength of blue light (around 468–470nm).[13] Broad-spectrum multi-peak LCUs have been gaining popularity because they deliver both violet and blue light, and the manufacturers claim they will photoactive all known dental resins.[8,23,20] However, when the wavelengths of light transmitted through the CAD/CAM block were examined, it became evident that the light attenuation increased with increasing resin composite thickness and was much greater for the violet light (Figures 3 and 6). Thus, if the resin cement requires violet light to be optimally cured, this is a problem. It may also be problematic if the clinician chooses to photo-activate a bonding agent that requires violet light through the overlying restorative material. However, some companies have developed resin cements that use Norrish Type I photoinitiators (Ivoclar, Schaan, Liechtenstein) that are more efficient and require fewer photons to produce free radicals than Type II photoinitiators.[38] These Type I photoinitiators do not require co-initiators, they are less yellow in color and have higher absorptivity.

This study shows that the choice of LCU, luting material, shade, thickness of the restoration, and the exposure time all influence the amount of transmitted light. This study has limitations because the light transmission was measured only through flat surfaces of the CAD-CAM material. Another limitation is that only correctly functioning LCUs and one CAD-CAM material were tested in this study. Other products and LCUs may have different outcomes.[7,23,34,35] The operator technique, the light source (LCU), and the direction of light will all affect the amount of light delivered such that the polymerization obtained clinically may sometimes be much less than that achieved under ideal laboratory conditions.[14] Some clinicians use flowable or heated high-viscosity light-activated resin composites to cement their CAD-CAM restoration.[20] This decision should be carefully reconsidered as the thickness of the CAD-CAM material increases. Clinicians should be careful when faced with a clinical situation with greater restoration thickness in hard-to-reach locations, such as second molars, and with dark or white opaque shades.[30] A dual-activated resin cement should be used if the restoration is greater than 1 mm thick.[11] The clinician should ensure that the light of the LCU has a direct straight-line access to all the surfaces of the restoration, and none of the resin cement should be in shadow.[24]

Conclusion

Within the limitation of this study, the following conclusions can be drawn:

a. As the thickness of the tested CAD-CAM material increases, the radiant power and the spectral radiant power of the transmitted light from all tested LCUs decreased exponentially.
b. The A3.5 shade of the tested CAD-CAM material had higher light attenuation than the Bleach and A2 shades using any of the tested LCUs.
c. VALO Grand and Elipar DeepCure delivered the most homogenous light and greater radiant power compared to Optilight Max.
d. The violet light from the VALO Grand multi-peak LCU was undetectable when the CAD/CAM material was 2.0-mm thick.

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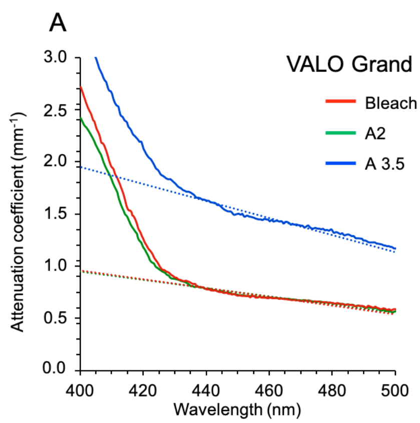
See a correct Figure 6.



https://doi.org/10.1590/1807-3107bor-2023.vol37.0114.erratum